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Energy consumption in schools – A review paper

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ABSTRACT

Among all public buildings, on account of their educational purpose, school buildings have a major social responsibility. Therefore energy performance in this type of building is of great importance.

The overall purpose of this research is to achieve a functional benchmarking, based on the real operation conditions of school buildings, by the exploitation of the results made public, through an intensive literature survey on energy consumptions in schools.

The survey was made to gather data that is relative to energy consumption in school buildings, documented in the most diverse fields and units: global energy consumption values, electrical energy consumption; fuel consumption for heating, energy data consumption of schools expressed in annual cost per unit of heated/cooled surface area ($/m^2) or per unit of heated/cooled volume ($/m^3) or, finally, as the annual cost per student ($/student).

The literature was analyzed to determine if a worldwide comparison among the published data could be established.

The results suggest that when attempting to determine an energy benchmark some considerations should not be forgotten: standard indoor environmental conditions (IEC) for classrooms (set-point for indoor operative temperature of 20 °C in winter and 26 °C in summer as suggested in EN 15251:2007), electrical and heating consumption values should be kept separately, different education levels usually require different energy consumption values. A good way to normalize heating energy consumption is going through a climatic adjustment based on Heating Degree Days (HDD). For an impartial data comparison, based either on an operating rating or on a simulation carried out for reference conditions, benchmark reference values should be expressed in terms of billed energy data.

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1. Introduction

1.1. Aim and scope of the paper

In 2002, the Energy Performance of Buildings Directive (2002/91/EC) [1] introduced the mandatory energy certification of buildings in the EU from 2006. Within this context, all the Member States (MS) proposed different Energy Performance Certificates (EPC) exhibiting different information expressed into distinct scales. A similar process has been taking place in the US [2–6], Canada [7] and Australia [8].

Public buildings with public ownership, like schools, represent an important opportunity towards energy efficiency and suitable Indoor Climate Quality (ICQ) levels representativeness. School buildings "can be used as communication means towards pupils and their families, and can thus reach many different society groups" [9]. Because of their high number in the total state building stock, they contribute to a considerable part of the overall amount of energy consumption, and consequently of the expenses paid by the national budgets [10]. School's energy use do highly contribute to schools' running costs – after salaries of teachers and staff, energy costs are the second most significant expense [11].

Worldwide studies and publications present different energy consumption ratios on different descriptors, sometimes with different units and several energy use types. Besides, different approaches/methods lead to barely comparable values. These data characteristics have been summarized in Table 1.

Discrepancies between design estimates and actual energy use have been verified which makes the comparison of measured and calculated values substantially difficult. This is verified because a rating based upon real measured consumptions is influenced by the behavior of the occupants and the calculated values are obtained by computational simulation depending of predetermined load and occupation profiles, which in some cases are very different from the real ones [12–14]. Besides that, some simplifications assumed in simulations and the random character of weather conditions may contribute to increase the discrepancies.

The study herein presented is organized according to the methodology of literature review presented in Section 2. It summarizes and explores the peer-reviewed literature on energy

Table 1
Comparison of data characteristics used in energy consumption literature analysis.

Location	Energy type	Unit (per annum)	Reference value	Literature	Year of publication
Austria		kWh/m²		[18]	2010
Cyprus	*Billed energy*	kWh/m²	Typical :average	[19]	2014
Czech Republic	*Delivered*			[15]	2011
Denmark	Primary	kWh/m²		[15,20,21]	2011, 2013
Finland	–	kWh/m²	Average	[9,22]	2010
Flanders	–	kWh/m^2		[23] *cit in* [24]	2002, 2008
France	Primary	kWh/m²	Average	[25]	2012
Germany	Primary	kWh/m²		[26–28]	2013, 2011
Greece		kWh/m²	Average, typical and good practice	[20,29]	2011
Hungary		kWh/m²		[27]	2011
Italy	Primary	kWh/m²	Mean	[18,30–33]	2002, 2008, 2010, 2013
Northern Ireland	*Consumed energy*	kWh/m²	Typical and good practice	[34,35],	1997, 2000
Poland		kWh/m²		[27]	2011
Portugal	*Consumed energy*	kWh/m²	25% percentile median	[16,20]	2011, 2013
Slovakia		kWh/m^2		[9]	2010
Slovenia		kWh/m^2 kWh/m^3		[36]	1999
Spain		kWh/m²		[27]	2011
Sweden	Primary	kWh/m²		[20,27,37]	2011, 2013
United Kingdom (UK)	*Consumed energy*	kWh/m^2	Good practice: 25% percentile typical: median	[38,39]	2003, 2004
Argentina	*Consumed energy*	kWh/m^2	Average = mean	[40]	2000
Canada	*Billed energy*	kWh/m²		[41] *cit in* [29,42,43]	2010, 2013
USA		*kBtu/ft²* $/$m^2$ $/student	Median, 25% percentile	[44–46]	2010, 2008, 2012
Hong Kong		MJ/m^2		[47]	2013
Japan		GJ/m²	Average	[48]	2008
Malaysia	*Billed energy*	kWh/m²	Best practice	[49]	2012
South Korea	*Consumed energy*	MJ/m^2 MJ/student	Average	[50]	2012

Nomenclature

AEB	All-Electrical Building
BEI	Building Energy Index
CFA	Conditioned floor area
DEC	Display Energy Certificate
DHW	Domestic Hot Water
DOE	US Department of Energy
ECI	Energy Consumption Indicator
ENEA	Italian National Agency for New Technologies, *Energy and Sustainable Economic Development*
EPBD	Energy performance of buildings directive
EPC	Energy performance certificates
EUI	Energy use intensity
GFA	Gross Floor Area
HDD	Heating Degree Days
ICC	Indoor Climate Conditions
ICQ	Indoor Climate Quality
IEC	Indoor Environmental Conditions
IEQ	Indoor Environmental Quality
MS	Member States of the European Union
MMFB	Mixed mode fuel building
NFA	Net floor area
NZE	Nearly Zero Energy
OFA	Occupied floor area
OR	Operational rating
RES	Renewable Energy Sources
SBI	School Benchmarking Indicator
TUFA	Total useful floor area

consumption in schools. The reviewed existing data emphasizes the challenge of addressing the theme, considering the multiplicity of criteria for data presentation.

This paper aims at analyzing the school buildings typology (new and existing) in order to achieve a functional benchmarking based on the real operation conditions of buildings. Expectantly, this paper is comprehensive to determine the sufficient information and as a reference for further details on benchmarking energy consumption in schools.

Life-cycle energy consumption analysis of schools is a subject out of the scope of the present study.

1.2. The importance of energy performance certificates in benchmarking (or vice versa)

Among all public buildings, on account of their educational purpose, school buildings have a major social responsibility. Therefore energy performance in this type of building is of great importance, together with suitable levels of Indoor Environmental Quality (IEQ). Following the Energy Performance of Buildings Directive, at a European level, the MS propose different Energy Performance Certificates (EPC) exhibiting different information at distinct scales, namely continuous and stepped. A similar process has been taking place in the US and in Canada.

According to [15], circa 30% of the European MS "have experience with measured energy used for national/regional energy performance evaluation". On the other hand, most of EPC procedures are based on simulation/calculation methods and not necessarily on operational rating (OR). This means that no direct relation can be established between buildings' energy labeling and benchmarking. This idea was first defended by the authors in [16].

EPCs in public buildings, particularly in schools, could drive into energy benchmark hypothesis (for heating and electricity needs), based upon reference building types, driven, on their turn, from average/typical consumption values or good practice [17].

Through benchmarking, school facility managers can compare their school to how much energy a typical elementary, middle and high school in a specific geographic region should consume, assuming the same target Indoor Climate Conditions (ICC). Throughout benchmarking, substantial energy cost savings could be generated while improving the ICC of school facilities. In resume, it is a fundamental method to be implemented.

The information about the different sources that were considered for the literature review is summarized in Table 1.

1.3. Energy fluxes in buildings

Most of the times, the available data on buildings' energy consumption corresponds to the type of (primary) energy delivered to the building. Ideally, the total amount of energy consumption in buildings should be disaggregated by the final energy end-use (consumptions). Disaggregating energy data helps knowing where most energy is used. In the USA, "for schools in general, lighting, ventilation, heating, and cooling account for 80% of energy consumption"; Fig. 1, based on data available at [51], illustrates this scenario. The importance of this theme is later developed in Section 5.

2. Methodology issues and data

2.1. Energy use and CO_2 emissions

For this research, the comprehensive literature review approach was based on the research of published papers in peer-reviewed journals, online publications about the topic and analysis of other existing information, such as conference proceedings, regulation and standards and European Directives.

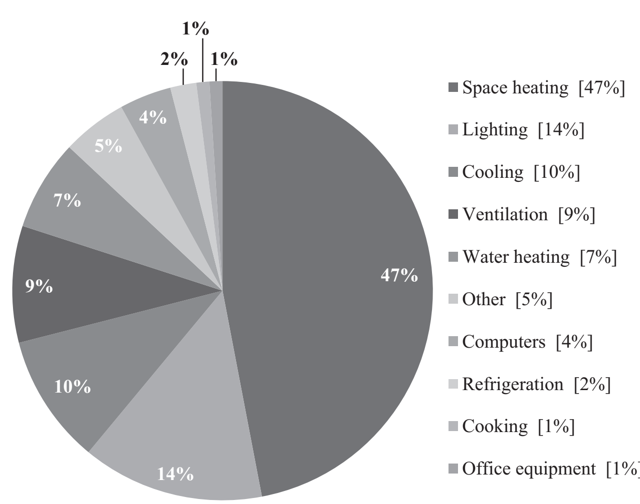


Fig. 1. Average energy use profile of schools in the USA.

Table 2
Energy consumption in schools and EPBD implementation

Location	Type of building	Indicators and units	Ref. value
Belgium [15] (Wallon Region)	New schools	• *Global* energy performance level (calculated *primary energy* consumption divided by calculated *primary energy* consumption of a reference building)	100
Czech Republic[15]	Education	• *Total* annual *delivered energy* consumption (heating, cooling, DHW, lighting, mechanical ventilation): kWh/m^2 per year • *Primary energy* and CO_2 are not assessed in EPC	90–130
Denmark [21,15]	Education	• *Primary energy* calculated consumption (heat, electricity, water): kWh/m^2 per year (primary energy conversion factors are being used in the calculation (primary/useful energy)).	95
Finland [9]	Schools and day care centers	• *E-value* requirements (overall maximum values for energy consumption): kWh/m^2 · year primary energy consumption (calculated with weight factor of energy source).	170
Slovakia [9]	Schools	• Energy class global indicator: kWh/m^2.year, *primary energy* (and also an energy class for heating energy)	205–272 (85–112)

2.2. Data analysis and energy use

This research was initiated at the European level, and then followed by American publications and finally Asian substance. Secondly, energy consumption data collection in schools was divided into general energy consumption, thermal energy consumption and electrical energy consumption, Section 3.

3. Energy consumption in schools

Data on global energy consumption in schools are the most commonly available in the literature. For global data it goes without saying uncategorized data, e.g. non-specification of energy type (primary or final energy), or data that refers to non-specification of building type (primary school, secondary school, schools with /without pool or canteen, etc.).

Although some authors have been showing that Display Energy Certificates (DEC) can be used to quantify school's energy consumption, and therefore allow a fair benchmark [15,52], only a minority of the EU countries have this category of buildings fully addressed on their national Energy Performance Certification legislation [15]. Table 2 refers to this appreciation.

But things are moving towards it [9]. "*Since 30th of June 2012, public bodies that occupy more than 1000 m² in a building must display an EPC on the front door or in the main lobby of the building*" [9]. The executive came into force in two phases, according to the category of the building being certified. Schools categories: nurseries, schools, colleges and universities fit in phase 2 (a list of the buildings to be certified since 1st of January 2012, and a list of those with an issued certificate since 1st of July 2012) [9]. In the Brussels Capital Region the certificate "is based on consumption data for electricity and fossil fuels used for all purposes, based on meters or invoices ", and "the EP indicator is calculated on the basis of the occupied floor area". An index of CO_2 emission is also foreseen. The mean value emissions and energy consumption anticipated for school and college buildings category is 40 kgCO_2/m^2 yr and 230 kWh/m^2 yr, respectively [9].

In countries like Belgium, e.g., the evolution on the requirements on maximum primary energy demand has been established, greatly based on the evolution on the evolution of the *U* values of the construction elements (walls, insulation levels) – for either new or existing buildings [15]. In the Flemish region, each new or renovated building has to fulfill requirements on EP (E-level): the annual primary energy consumption, divided by reference consumption. Since 1st of January 2012, the maximum E-level was also set at E70 for schools and office buildings [9]. Moreover, a new requirement on Renewable Energy Sources (RES) was recently added to the EP requirements and will be obligatory for all schools from 1st of January 2014; at least 10 kWh/m² yr of renewable energy will be needed [9].

Different MS have reached different levels of compliance within the EPBD. Starting from a common base, each country has been developing its regulations. In Cyprus, e.g., the Technical Services of the Ministry of Education and Culture are working in order to design and construct the first NZE (Nearly Zero Energy) schools [9].

In Slovakia, besides energy classes' scales for global indicators for schools (from 2013) where the global indicator is expressed in kWh/m^2 yr - primary energy, there is a rating scale for heating energy use. Class D corresponds to the reference value for the existing building stock [9].

In Austria, for instance, the maximum accepted space heating demand and *U*-values for new and existing buildings in case of major renovation was tightened. In Denmark, a major revision to EPC occurred in 2011. One of the changes is that the energy certification of selected buildings, such as educational buildings, can be based on the calculated or measured energy consumption [9]. In the Finnish situation, the new National Building Code sets maximum values for the energy consumption (*E*-values) calculated with the weight factors – for schools and day-care centers the value is 170 kWh/m^2 yr [9]. The values presented in Table 2 for Czech Republic correspond to Energy Label C – minimum required category for new schools and major renovations [15].

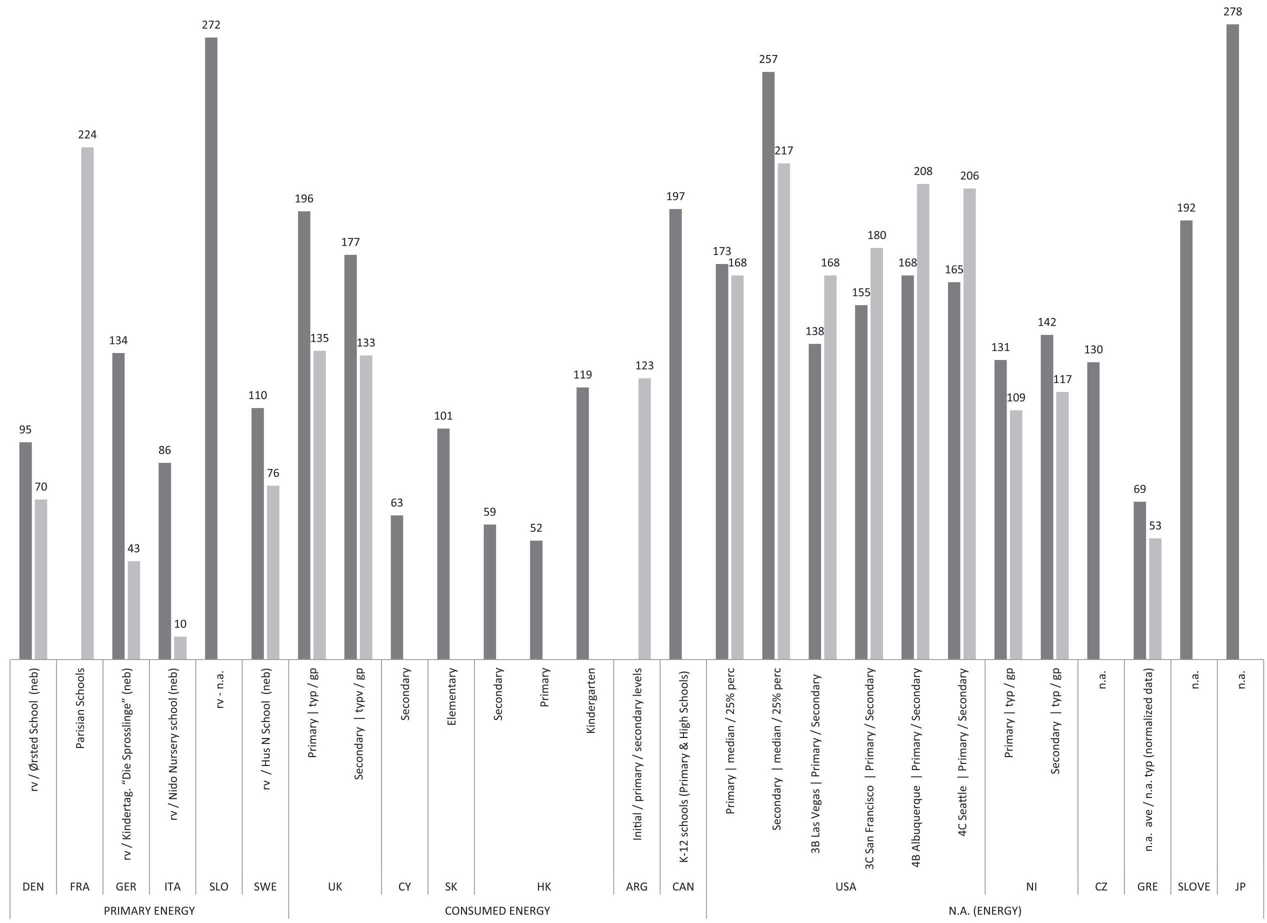
3.1. General energy consumption

In Denmark, one of the most experienced MS in EPC [15], the energy frame foreseen in the EPC system for schools provides information on the energy need for cooling, heating, ventilation, DHW and lighting [53].

The values found in the literature for Finnish schools [22], particularly in the Helsinki area, are presented both for *district heating energy use* and for the *total electrical energy use*. The values presented in Fig. 2 correspond to the sum of both and were determined by the authors.

Butala and Novak [36] presented the results of energy audits performed in 24 old school buildings in Slovenia, built between 1874–1969 and adapted between 1948–1996. Here, the average total energy values (heating, DHW, lighting) are expressed both in *square meter of building area* and in *per unit of volume of building*, 192 kWh/m^2 per year and 54 kWh/m^3 per year, respectively. The authors reinforce however that these values fall outside the range of accepted values of the Slovenian codes for energy use. On this paper, the authors provided also another indicator – heating energy per student, whose average value presented is 1646 kWh/pupil a.

In a recent publication [19], the annual energy consumption value presented for Cyprus schools, based on billed energy, is



Notes: DEN = Denmark; FRA = France; GER = Germany; ITA = Italy; SLO = Slovakia; SWE = Sweden; UK = United Kingdom; CY = Cyprus; HK = Hong Kong; ARG = Argentina; CAN = Canada; USA = United States of America; NI = Northern Ireland; CZ = Czech Republic; GRE = Greece; SK = South Korea; SLOVE = Slovenia; JP = Japan; rv = reference value; n.a.= non availabe (type of school building); EB = educational buildings; gp = good practice; typ = typical.

Fig. 2. Schools' annual global energy consumption values per country (kWh/m^2).

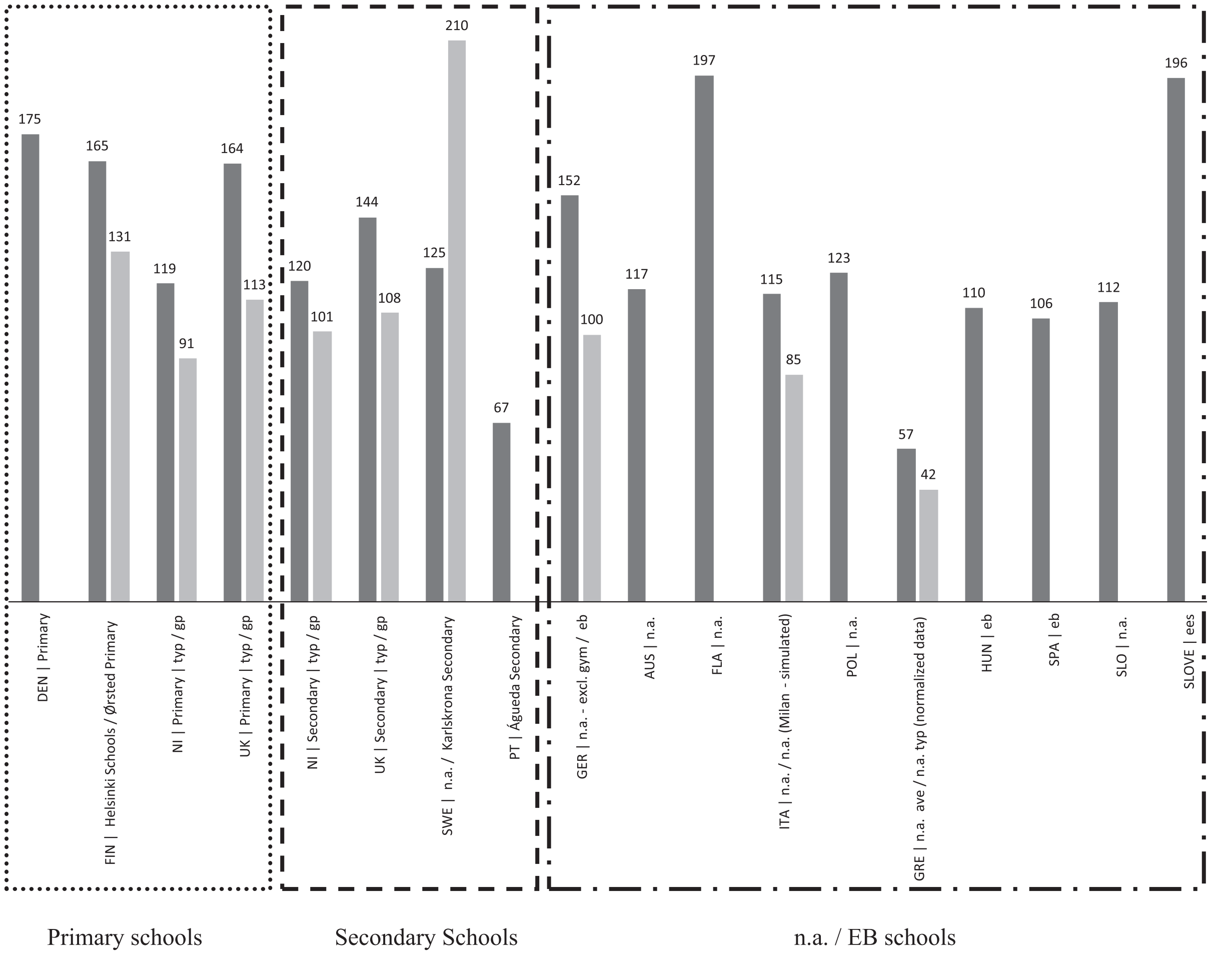
62.75 kWh/m^2 and 116.22 kWh/m^2, when expressed in primary energy.

The topic of energy relating to Hellenic schools has been abundantly published, [20,29,54–58]. Greek climatic zones definition has been changed. Within the previous regulation (*TIR*) there were three climate zones (A–C). KENAK introduced an additional climate zone (D) within the northern regions of the country (zone C) [58]. In 2011, Dascalaki and Sermpetzoglou [29] developed a comprehensive study aiming at assessing the energy performance of schools on a national level, embracing the three climatic zones (A–C), previously defined in Greece. The collected data was used to define "typical" values, in other words, energy performance benchmarks. From a total selection of 500 schools, the average thermal, electrical and total energy consumption was found equal to 57, 12 and 69 kWh/m^2, respectively. The data were normalized, allowing the authors to provide complementary values for *typical school* and *best practice* (25% percentile). This data is further depicted in Figs. 2–4.

In France, a recent program on energy renovation of schools is taking place in Paris. In March 2012 in a press release reported by the city mayor [25], the energetic profile of Parisian schools was revealed as 224 kWh/m^2. The value presented is expressed in terms of primary energy comprising all the energy consumption in the Parisian schools (half of those were constructed between 1880 and 1948).

In the early published Italian literature on the theme, 2002, three "behavior" categories for different types of schools [30] were found. Data presented in Table 3 sums up the *three behavior category* benchmark intervals. A curious aspect on this benchmarking systems is that both the *heating and cooling energy* needs are presented in terms of volume (non-residential buildings) and not of surface area (residential buildings) [15], which is the most common practice (energy consumption per gross floor area unit) – school height can vary significantly from school to school. It is also noticeable the fact that both heating and electricity energy indicators incorporate climatic info (fundamentally because in the same country there are alpine climatic zones up to very Mediterranean) – in the original unit $kWh_e/m^2xGGxanno$, GG (gradi-giorno) goes for degree-days (DD). This *intake* data is also common to other MS EPC, but normally under a climatic conversion factor.

In the Portuguese case, instead, the literature is relatively narrow, fairly unexplored. A first approach to energy consumption in secondary schools, based on 57 case studies data based electric billed, was presented in [16]. Moreover, the legislation is not as precise as in other countries – no specific legislation exists for



Notes: DEN = Denmark; FIN = Finland; NI = Northern Ireland; UK = United Kingdom; SWE = Sweden; PT = Portugal; GER = Germany; AUS = Austria; FLA = Flanders; ITA = Italy; POL = Poland; GRE = Greece; HUN = Hungary; SPA = Spain; SLO = Slovakia; SLOVE = Slovenia; n.a.= non availabe (type of school building); EB = educational buildings; gp = good practice; typ = typical; ave = average; ees = energy efficient school

Fig. 3. Schools' annual thermal energy consumption values per country (kWh/m^2).

school buildings. The national legislation, recently revised [59], foresees a B-energy efficiency label, at least, for new and major refurbished buildings in the service buildings sector. In this new legislation, the building energy efficiency is determined by comparing the buildings' simulated energy consumption with a reference building – in other words, with the buildings' simulated energy consumption if it was constructed, lighted and equipped with reference systems in which the building would have a B- label. The B- label corresponds to the median of the energy consumption, for the existing building stock, for the considered type of building.

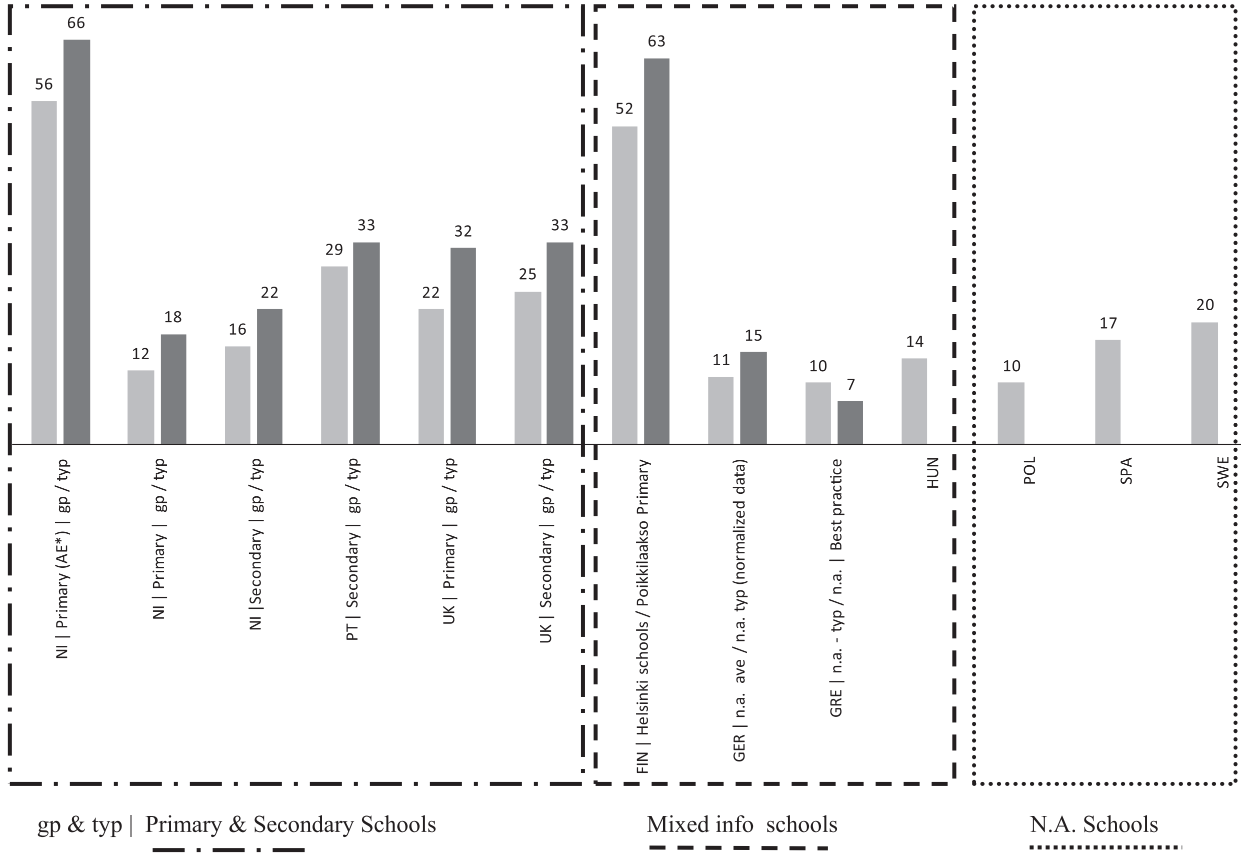
In the United Kingdom (UK), energy benchmarks in schools are calculated separately for fossil fuel and electricity, so that a school can determine performance against each benchmark for each type of energy use. This presupposition makes it possible that performance may be good for electricity but poor for fossil fuel or vice versa [38]. The values presented in Fig. 2 (determined by the authors based on [38]), Figs. 3 and 4 also highlight the difference between different education levels. The values herein presented do not consider schools with swimming pools.

It should be noted that "the median for schools is within 2% of the TM46 Benchmark" [60], (the DEC benchmarks are published as CIBSE Technical Memorandum 46 – a publication offering a complete figure of building energy benchmarks).

Similar to UK data presentation, data exposing benchmark values for Northern Ireland, presented in Figs. 3 and 4, do not consider schools with swimming pool. Data revealed by the authors of [35] highlights the importance of sub-categorization building types according to their typology (primary schools vs. secondary schools), but also different energy use, mixed-fuel buildings vs. all-electric. Although the authors of [35] defend that heating and electrical energy values should not be summed, for a general benchmark, the authors of the present paper present this summarized info in Fig. 2.

The evolution along time in the UK featuring energy benchmarks for DEC and improving energy performance in schools accounting for benchmarking is noteworthy [39,61–63]. Currently, more than 15,000 school buildings (university campus apart) are *databased* [60], corresponding to the second category (right after Hospital – clinical and research) more carbon intensive.

In North America, Canada, a reference table has already been designed (for different types of buildings) to help balance property's energy use to the national median [43]. Herein, the recommended benchmark metric is the *national median source* – Energy



Notes: AE = All Electrical school buildings; NI = Northern Ireland; PT = Portugal; UK = United Kingdom; FIN = Finland; GER = Germany; GRE = Greece; HUN = Hungary; POL = Poland; SPA = Spain; SWE = Sweden; n.a.= non availabe (type of school building); EB = educational buildings; ave = average; gp = good practice; typ = typical.

Fig. 4. Schools' annual electrical energy consumption values in European countries (kWh/m^2).

Table 3
Specific energy consumption reference values for Italian schools.

Annual energy	Nursery schools		Elementary schools		Middle, secondary schools	
	Heating ($Wh_t/m^3 x DD x year$)	Electricity ($kWh_e/m^2 x DD x year$)[a]	Heating ($Wh_t/m^3 x DD x year$)	Electricity ($kWh_e/m^2 x DD x year$)	Heating ($Wh_t/m^3 x DD x year$)	Electricity ($kWh_e/m^2 x DD x year$)
Good	< 18.5	< 11	< 11	< 9	$< 11{,}5$	< 9
Sufficient	$18.5 < x < 23.5$	$11 < x < 16.5$	$11 < x < 17.5$	$9 < x < 12$	$11.5 < x < 15.5$	$9 < x < 12$
Insufficient	> 23.5	> 16.5	> 17.5	> 12	> 15.5	> 12

[a] The e subscript kWh goes for electrical energy – to better distinguish the energy type.

Use Intensity (EUI), expressed in GJ/m^2. The value presented in Fig. 2, expressed in kWh/m^2, was determined by the authors using a web energy converter. The median value corresponds to the middle of the national population of a certain type of building. Fig. 2 presents the median value for *site EUI* (197 kWh/m^2). Since *site EUI* results in a mixture of energy (primary energy plus secondary energy, depending on the type of energy provided to the building, e.g. raw fuel like natural gas vs. a converted product like electricity), *source EUI* use is recommended (in this case, the median value is 283 kWh/m^2).

In the USA, a different approach is found in the literature. Normally, energy data consumption of schools are expressed in *annual cost per surface area* ($/m^2) or *annual cost per student* ($/student), [45]. In other situations data is present in *kBtu* (one thousand British thermal units) [46], making a worldwide comparison of the energy values difficult.

The current DOE (Department of Energy) building benchmark models are quite complex and representative of the U.S. housing stock, located in different climatic locations in the U.S. Among the models there are various building types, including primary schools and secondary schools. The climatic zones classification adopts the methodology of the ANSI/ASHRAE/IESNA Standard 90.1-2007 *Normative Appendix B – Building Envelope Climate Criteria.* Herein each climatic zone is classified by a number (1–8) representative of air temperature air distribution and by a letter (A–C) representing the humidity level, which for North America depends mainly

on the longitude. The data processed by the authors from the available information [44] for primary and secondary schools in the 8 climatic zones (mean and 25% percentile values) is presented in Fig. 2. Moreover, general energy consumption values for climatic zones 3B, 3C, 4B and 4C are presented too.

The values presented in [50], relating the average energy consumption of the elementary schools in South Korean schools, are expressed in MJ/m^2 yr in terms of annual energy use (electricity, oil and gas) and per capita, ranging between 2951 MJ/student y to 3889 MJ/student y. The values presented in Fig. 2 correspond to the sum of the three fuel types (energy consumption per unit area) – 365 MJ/m^2 were determined and converted by the authors: 101.4 kWh/m^2. Almost 72% of this global value corresponds to electric energy use.

In Malaysia (2012), aiming at reaching 2020 more intensive requirements, a study was driven in a university campus [49]. By considering the total annual (electric) bill, it was observed that this university building energy index (BEI) was 116 kWh/m²/yr, lower than *the best BEI practice* and recommended value by the Malaysian Standard 1525 for non-residential buildings: 135 kWh/m²/yr.

The annual average energy consumption value for educational buildings in Japan (from kindergarten until university) presented in [48] is 0.36 GJ/m². The value presented in Fig. 2, of 277.8 kWh/m^2, was converted by the authors. The influence of the University level on the average value presented is worth mentioning, since all the buildings in this category present a consumption value close to 0.5 GJ/m² or higher. The energy use intensity of this educational level might justify the significant differences towards the other Asian countries herein presented.

The Electrical and Mechanical Services Department (EMSD) of the Government of the Hong Kong SAR Government makes available some Energy Consumption Indicators (ECI) for diverse business operations [47]. Nevertheless, because these are derived from studies on a limited size of samples within the population of respective energy-consuming groups, this entity states they "*should not be construed as representative energy consumption levels of the population, nor as territory-wide standards which businesses in the respective energy-consuming groups should comply with*". Yet, it is interesting coming across ECI for different education services. Values in the literature are presented in MJ/m^2. In Fig. 2, the values are expressed in kWh/m^2 to allow a better comparison. It should also be added that this entity provides one online benchmarking tool, where one of the filling fields is *internal floor area* (IFA), not differentiating whether it is net floor area (NFA) or conditioned floor area (CFA).

The difference towards the commonly variable found in literature – *gross floor area* (GFA) – is noteworthy. In some other cases *total useful floor area* (TUFA) is the considered reference floor space used for benchmark [60]. Many times, the energy reference area is not explicitly defined.

3.1.1. Thermal energy consumption

The study on energy consumption on Slovenian schools previously presented [36] introduces an *energy number for heating* in energy-efficient school buildings, varying from less than 112 kWh/m^2 per year to 196 kWh/m^2 per year, and referencing a maximum of 1 MWh/pupil per year.

In Finland, Helsinki schools' *district heating energy use* is presented in [22] as an average degree-day-adjusted value. A similar approach is also validated in [29]. Herein, stated values for *typical school* and *best practice* correspond to normalized data, taking in account climate variations as well as the operating time among the schools of the sample.

In the UK, schools' benchmark is measured in kilo-watt hour (kWh) per m^2 of *heated floor space* per annum for fossil fuel and electricity. Based on consumption data for 2000 schools in England in 1999–2000, in [38] both *typical* and *good practice* values are presented. The typical value corresponds to the median value of the data. The good practice value matches the lower quartile of the data; this means "25% of schools sampled performed better than the good practice benchmark" [38]. The typical value for primary and secondary schools for fossil fuel is 164 kWh/m^2 and 144 kWh/m^2, respectively.

The interval presented as Slovakian reference heating energy use reference values (85–112 kWh/m$^2\cdot$yr), corresponding to the reference value for the existing building stock [9], class D of the national EPC.

In Italy, for high schools and offices the conventional heating period was fixed at 6 h per day [31]. In the study by Corgnati et al. 2008, space heating average values vary between 110–115 kWh/m^2 (37–38 kWh/m^3). These values are obtained from a sample of more than 100 schools in the region of Piedmont (northwest Italy, near the Alps). The authors also revealed that the deviation of the profile was quite high, highlighting the heterogeneous profile of Italian school buildings in terms of energy performance. Nevertheless, the specific energy consumption frequency distribution showed a regular profile around its mean value, for which the authors defended the values obtained by the statistical analysis could be taken as benchmarks for building classification purposes within the national energy certification schemes.

Shortly after, in 2010, ENEA's (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) report RSE/2010/190 [32] reveals complementary information on the period of use of scholastic buildings. 70% of the school buildings have morning and afternoon courses (9 h) and 20% have evening courses, being operational for 14 h/day. It is also noteworthy that more than 30% of these present extra-curricular time use. Complementarily, this report adds that only a fourth of the school buildings adopt a partial heating time table in relation with the hours of use of the building. The average heating energy value herein presented is 27 kWh/m^3 – expressed as specific consumption of *useful energy* (referred to the unit of gross heated volume), lower than the one previously presented in [31].

Interestingly, these Italian values, when compared to the simulated ones under the European project COMMONCENSE (financed by the Intelligent Energy program [64]), are considerably higher. For the scholar buildings in Rome and Milan, the estimated heating energy loads intervals were 24–32 and 73–85 kWh/m$^2\cdot$yr, respectively [18].

On this same report [18] estimated values are found for heating energy loads and final HVAC energy systems in Austria according to the different comfort and ventilation categories stipulated in EN15251 [65]. The estimated energy intervals were 95–117 kWh/m$^2\cdot$yr and 119–146 kWh/m$^2\cdot$yr, respectively.

The values presented in [27] relating fuel consumption (data presented for Germany, Sweden, Hungary, Poland and Spain) are somehow adjusted, since they correspond to calculated useful heating demands with a BEAM model, which took into account typical national heating system efficiencies (the useful energy demand was transferred to end energy consumption). On the other hand, electricity consumption values (presented in Fig. 4) are based on Ecofys calculations and metered data from *Rotermund, KG, 2010* – a report that investigates more than 2800 non-residential buildings.

“Mixed Info Schools” in Fig. 4 refers to situations where the information is not structured in the same way and some assumptions or generalizations had to be done during the data analysis.

The study developed by Filippín [40] revealed that in Argentine schools (the sample involved schools from the initial, primary and secondary levels), gas consumption (directly related to heating consumption) accounted for about 90% of the total energy

consumption. Pitifully, only general values are expressed in kWh/m^2 per year; thermal energy is totally accounted for, but not as an indicator. Curiously, this author also presents energy consumption values in terms of CO_2 emissions 20–60 kg CO_2/m^2 (average 31.4).

3.1.2. Electrical energy consumption

In a Finish case study of a small primary school, presented in [22], the total electrical energy use for lighting, HVAC and equipment is compared with the average electricity use in Helsinki schools –52 kWh/m². It is noteworthy that these values follow UK's [38]. But since no data relating heating energy was presented in [16], it is not possible to affirm whether these schools perform as efficiently as the ones in the UK. They just perform similarly in terms of electrical consumption.

Later in 2013, energy consumption data from refurbished school buildings in Portugal under the *Modernization of Public Secondary Schools Program* [66] launched by the Portuguese government in January 2007 were previously presented in [16]. These values relate solely electrical energy consumption. It is noteworthy that the heating system in modernized Portuguese schools presented in [66,67] and [16] does not necessarily rely on fossil fuel; hence, the values in [16] might, in fact, reveal a better general energy consumption than those in the UK. This presumption can only be validated if new data related to heating energy consumption comes to light.

3.1.3. Normalized energy costs

In the USA K-12 schools represent approximately 8% of the energy use and 10% of the floor area in service buildings nationwide, spending more than $8 billion each year on energy [51]. As previously presented, the USA's approach to energy consumption in schools is more incisive on energy cost per student. One of the most recent studies [45] in the field reveals that in Texas, for example, students' energy cost can vary as much as $75–$200 per year. Moreover, it has been remarked how these values can appear deceiving by misconsidering building space utilization – "variations in space utilization can skew benchmarks for building performance". Almost 70% of the schools in Texas have an actual student density between 75–200 square feet per student, but all the other varied "widely in sq.ft./student, energy cost/student, or both" [45]. Other publications [68,69] showed "schools spend approximately $75 per student on gas bills and $130 per student on electricity each year" citing U.S. Environmental Protection Agency (EPA) data from 2008.

In 2012 [46], using EPA's data, median energetic cost between 1.3 and 1.38 $/ ft^2 is presented, for different types of school – elementary, middle or high. In another case study, in the Vigo County School Corporation (VCSC) in Terre Haute, Indiana, which is composed of "3 high schools, 2 alternative schools, 6 middle schools, and 18 elementary schools", after a retrofit program, an Energy Cost Intensity of $0.70/$ft^2$ was found [51] – half of the cost intensity value in ASHRAE 90.1-2004, $1.40/$ft^2$. St.Thomas School new school building in Medina (the first LEED® for Schools Gold Certified project in Washington State) presents an even more impressive value $0.43/$ft^2$ and EUI of 71.3 kBtu/ ft^2 per year [70].

Authors like [45] recall, nevertheless, the determinant character of climate adjustment and weather normalization, separating them into more-humid coastal areas and less-humid non-coastal areas. This points out the importance of school location and how this increases energy consumption and costs – normalized energy costs should not be regarded isolated but always in a context (this theme is later developed in Section 5).

4. Benchmark categories: schools typology

Monitoring and targeting provide mechanisms for the long-term management of energy use and for highlighting potential improvements in the efficiency of energy use [39]. A minimum period of data collection is necessary to provide a useful comparison between a certain building typology.

To allow an understandable comparison between the values from different countries the authors defend that *final energy consumption*, the value that comes on monthly energy bills, should be used as the unit for benchmark – more developments in Section 5.2 **– Benchmark unit**. A School Benchmarking Indicator (SBI) is proposed (previously presented by the authors in [16]) based on the metered energy use and is intended to reflect the operational characteristics of a school building: in contradiction to the EPCs that reflect the design characteristics – theoretical energy performance of buildings, based on standardized data and assumptions that do not necessarily reflect true energy performance.

ENEA's report RSE/2010/190 [32] discloses the importance of statistical consistence of data. Using statistical analysis tools, several variables were examined to verify the ability to explain part of the variation of the energy consumption. It was found that the factor that most influences the energy consumption for heating and energy electricity in school buildings, among the analyzed sample, was the surface area and/or volume (mostly volume). In some cases, it was also verified to have a significant influence on the heating consumption; the data related to the transmittance of opaque components of the façades, the boiler power and daily period of use (n° hours). As regards the electrical consumption, building surface area was found to be the most significant variable, the one explaining most of the phenomena variation.

The efforts to define coherent figures to be used as benchmarks raises several questions:

1) choosing the *building typology* or subcategory;
2) defining the *typical energy use* of a certain building;
3) establishing appropriate reference values for the definition of *good practice energy use;*
4) finding a suitable weather adjustment factor.

4.1. Schools' typology: typical building definition

Primary and secondary schools have different energy use, different occupancy density, different hours of use, etc. Therefore, to assure the quality/accuracy of data, like establishing the floor area definitions being used, a primary distinction between scholar degrees should be established. The authors defend that primary and secondary schools correspond to different educational buildings category. The year of construction should also figure in the final picture. From the reasons already presented and based upon all the literature on the theme, the authors suggest that the *typical value* should correspond to the *median value* of the sample, avoiding the disadvantages of choosing the mean, which can be biased by extreme values, and might not be absolutely representative if the data distribution is asymmetric. When *typical* and *good practice* values are addressed, the tendency is that the last one corresponds to the 25% percentile; this means that 25% of the sampled buildings have lower energy consumption than these benchmarks.

4.2. Mixed-mode fuel buildings vs. all-electric schools buildings

In [35], the authors draw attention to the different fuel energy uses in buildings. Two fuel types have different costs, primary

energy use, and CO_2 emissions, and hence should be kept separate. Mixed mode fuel buildings (MMFB) have necessarily different energy consumption from all-electric school buildings (AEB). Curiously, some of the most recent buildings running for NZEB, *selected best-practice buildings*, are *all-electric buildings* (PV and heat pump), for example, the *Enerpos* school in St. Pierre, La Reunion, France [71]. This assumption implies that MMFB and AEB define different SBI categories.

Moreover, the authors defend that electricity and fossil fuel consumption should be kept separate. More information is presented in Section 5.3 **– different energy uses, different indicators**.

4.3. Heating degree days – data climate adjustment

Although some authors do not defend that [35]: "the data analysis did not adjust the raw data in any way, e.g. weather correction, as this kind of normalization can often bring in more inaccuracies than it removes, masking the true trends in consumption", when attempting an all-in-one benchmarking, climate location cannot be disregarded. Further discussion is presented in Section 5.1.

5. Data normalization – discussion

This section will discuss three topics related to the considerations on data normalization of energy consumption in school buildings: weather adjustment; benchmark unit; different energy uses, different indicators.

5.1. Degree Days – data climate adjustment

Data normalization is a complex issue. For an impartial data comparison, the recalled SBI [16] accounted for metered energy consumption and climate differences adjustments, resulting in a combined unit – kWh/m^2/yr/HDD (where HDD stands for Heating Degree Days). This approach is already in practice in some countries' data presentation, as in the cases presented in [30] and [46].

5.2. Benchmark unit

It is true that *billed* energy consumption in school building is influenced by users' behavior. It is also true that asset ratings, because they are based on estimated calculations, often do not consider the real period of occupation of buildings, the accurate efficiency coefficient of the heating plant, the *unregulated energy* (general appliances, computers, non-fixed systems) [72], or *slippage during construction and commissioning* (the building may not be constructed exactly as intended or may not be occupied quite as envisaged), [73].

The authors defend that benchmark should be withdrawn from *billed* energy consumption, i.e. using an operational rating (OR). Foremost because significant differences between simulation and real use buildings have been found[14], what Bordass et al. [73] called the 'credibility gap' between predicted and actual energy use. However, this is also because of the trend of some of the MS energy policies [9]. Moreover, assuming a temporal development, this will allow school managers to check their school energy evolution in time – the previous OR should be shown.

The unit kWh/m^2 found in the literature is varied and often imprecise, relating to the type of area under reference, i.e., GFA, NFA, OFA, TUFA, etc. Ideally this unit should refer to the conditioned floor area (CFA).

5.3. Different energy uses, different indicators

At the same time, because gas and electricity consumption is not always used for the same purpose – for example, heating in schools is not always assured from gas – as previously presented in Section 1.3, it is proposed that the breakdown of the total amount of energy is by final energy end-use, according to Fig. 1**,** or at least that electricity and gas consumption should be kept separately, resulting in two different indicators, imbued with the Finish approach [15]:

a) *Gas consumption: for space heating* & *domestic hot water (DHW);*
b) *Electricity consumption: for lighting, HVAC systems* & *electrical equipment.*

Very often only billed data is available. Within this approach, it is possible to allocate consumptions even if the final energy end-use is unknown. Although not ideal, this policy allows a higher level of detail compared to the one more often presented in the literature.

One of the potential benefits of the SBI is encouraging the generation of a national database of building energy performance to assist in better informing policies, a mean of promoting better standards for energy management, and a continuous evaluation. The comprehensive review of Perez-Lombard et al. [74] describes how building energy certification schemes for existing buildings should be implemented by using operational ratings with reference values (benchmarks) taken from the building stock.

6. Conclusions

The presented study should be considered as a contribution to the issue of energy consumption of school buildings' benchmarking, for which there should be further developments, checks and additions. Therefore, the obtained results are an assessment of the magnitude of the problem and potential of its solution.

The breadth of the term *education buildings* embraces different-sized schools (elementary, primary, secondary school buildings) that offer different education levels, which entail a wide gap in the energy needs even among buildings with the same general use classification. Different school levels anticipate different occupation densities and time-table occupation and therefore different energy consumptions. The same reasoning can be applied to the difference between high schools and university buildings. In the context of USA, for instance, the difference between primary and secondary schools can correspond to almost 50% increase in terms of the global energy consumption (173 vs. 257 kWh/m^2). This value is quite contrary to that of the UK's – in this case, secondary schools' global energy consumption is 10% lower than primary schools' (196 vs. 177 kWh/m^2).

Moreover, it is defended that besides the building's standard use – teaching, other specific facilities such as swimming pools should be analyzed separately.

In agreement with other authors, recall [35], the importance that small sample sizes (<50 buildings, [61]) might have on misleading is emphasized and therefore it does not provide a useful analysis. Care should be taken when comparing a particular building with the benchmarks based on non-significant samples.

Statistical benchmarks based on buildings' *billed energy consumption*, databased on a national level, are to be developed – this is already in practice in the UK (DCLG – Department for Communities and Local Government) [72], in Germany (GEFMA – *Rotermund Ingenieure and the German facility Management Association*) [27] and in the USA (DOE – Department of Energy), [75]. In the UK, for example, it has been verified that typical global energy

consumption values vary between 177 and 196 kWh/m^2, in primary and secondary schools, which is very similar to Canadian k-12 schools (both primary and secondary), 197 kWh/m^2.

Comparisons of the presented values are difficult and might be fallacious. By looking at data in Fig. 2, for example, it would be unfair or even incorrect to state that schools in a certain country spend more energy than in the UK, since we do not know the energy resources combination of the consumed energy that would allow us to convert it into primary energy. We observe that typical thermal energy consumption values are 14% higher in primary (164 kWh/m^2) UK schools than in the secondary level (144 kWh/m^2), but we also observe that in Northern Ireland typical values are practically the same in both educational levels – 119 and 120 kWh/m^2. These parallelisms, recalling Fig.3, cannot be so strongly established between Northern Ireland and Hungary, for example. Data presented for Hungarian educational buildings does not refer to the educational level.

Moreover, it has been verified that different energy "feed" buildings have different energy performances, for which mix-mode buildings and all-electrical buildings should be approached differently.

Under any circumstances, energy benchmark of the school buildings is to be achieved by compromising indoor thermal conditions or indoor air quality of the school buildings.

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